Construction of e-Permit/VWS Model Sites
Project Summary Report

Laurel, Kentucky and Unicoi, Tennessee

FHWA-HOP-18-016

Final
Report

U.S. Department of Transportation
Federal Highway Administration

February 2019

FORWARD

This report summarizes the development, installation, testing, and deployment of two virtual weigh station “Model Sites” as part of the Federal Highway Administration’s (FHWA) Smart Roadside Initiative” (SRI).

Rising commercial traffic volumes, staffing cuts, and expanding roadside enforcement personnel roles and responsibilities are stretching the ability of States to conduct effective commercial vehicle enforcement. To address this, the FHWA Office of Freight Management and Operations and the Federal Motor Carrier Safety Administration’s (FMCSA) Technology Division deployed two virtual weigh station (VWS) ‘Model Sites’ on U.S. 25 in Laurel County, Kentucky and on Interstate 26 in Unicoi County, Tennessee. VWS provides screening and monitoring capabilities like that found at fixed weigh stations but does not require continuous human staffing and can be deployed at a lower cost than a fixed site. The two ‘Model Sites’ are intended to demonstrate the functionality and viability of VWS and advance the “Smart Roadside Initiative” (SRI) concept developed by FHWA and FMCSA.

Following installation and calibration, a site performance review began to ensure that the above functionality was met. Each site utilized the SmartRoadside Inspection System (SRIS) as an automated tool to assist enforcement officers in screening commercial vehicles. Overall system performance was found to be good.

An independent analysis by Oak Ridge National Laboratory (ORNL) found that the Unicoi County, TN site was working reasonably well but that the Laurel County, KY site was not functioning properly, the project team was given an opportunity to re-run some of their performance tests to potentially record a higher system performance. However, the project team believes that the recommendations made by ORNL showed gaps in definitions and understanding of the SRIS system operation and thus the ORNL analysis presents differing performance numbers. The project team conducted the initial proscribed performance analysis with results consistent for the site conditions and equipment deployed. The performance numbers officially collected by the team meet the project goals and expectations of the system and continue to do so in subsequent monitoring. The sites began full operations in May, 2016.

The interested audience for this report includes FHWA, FMCSA, State Departments of Transportation, State enforcement personnel, and others who are involved in commercial motor vehicle (CMV) size and weight enforcement.

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16. Abstract:

Rising commercial traffic volumes, staffing cuts, and expanding roadside enforcement personnel roles and responsibilities are stretching the ability of States to conduct effective commercial vehicle enforcement. To address this, the Federal Highway Administration's (FHWA) Office of Freight Management and Operations and the Federal Motor Carrier Safety Administration's (FMCSA) Technology Division deployed two virtual weigh station (VWS) 'Model Sites' on U.S. 25 in Laurel County, Kentucky and on Interstate 26 in Unicoi County, Tennessee. VWS provides screening and monitoring capabilities like that found at fixed weigh stations but does not require continuous human staffing and can be deployed at a lower cost than a fixed site. The two 'Model Sites' are intended to demonstrate the functionality and viability of VWS and advance the "Smart Roadside Initiative" (SRI) concept developed by FHWA and FMCSA.

Following installation and calibration, a site performance review began to ensure that the above functionality was met. Each site utilized the SmartRoadside Inspection System (SRIS) as an automated tool to assist enforcement officers in screening commercial vehicles. Overall system performance was found to be good.

An independent analysis by Oak Ridge National Laboratory (ORNL) found that the Unicoi County, TN site was working reasonably well but that the Laurel County, KY site was not functioning properly, the project team was given an opportunity to re-run some of their performance tests to potentially record a higher system performance. However, the project team believes that the recommendations made by ORNL showed gaps in definitions and understanding of the SRIS system operation and thus the ORNL analysis presents differing performance numbers. The project team conducted the initial proscribed performance analysis with results consistent for the site conditions and equipment deployed. The performance numbers officially collected by the team meet the project goals and expectation of the system and continue to do so in subsequent monitoring. The sites began full operations in May, 2016.

17. Key Words
Truck Size & Weight, Virtual Weigh Station, Automated Truck Enforcement

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	**Definition**
ALPR	Automated License Plate Reader
ASTM	American Society for Testing and Materials
AUNR	automated U.S. Department of Transportation (DOT) Number reader
AUR	Automated USDOT Reader
CDL	commercial driver's license
cf	conversion factor
CMV	commercial motor vehicle
CMVRTC	Commercial Motor Vehicle Roadside Technology Consortium
DOT	Department of Transportation
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operation test
GPS	global positioning system
GVW	gross vehicle weight
ITD	Innovative Technology Deployment Program (Formerly CVISN)
ITS	Intelligent Transportation Systems
KATS	Kentucky Assistive Technology Service
ORNL	Oak Ridge National Laboratory
OVC	overview camera
SRI	Smart Roadside Initiative
SRIS	Smart Roadside Inspection System
THP	Tennessee Highway Patrol
USDOT	U.S. Department of Transportation
VDIM	Vehicle Dimensional Measurement
VWS	virtual weigh station
WBS	Work Breakdown Structure
WIM	weigh in motion

CHAPTER 1. INTRODUCTION

In response to increasing commercial traffic volumes, staffing cuts, and the expansion of roadside enforcement personnel roles and responsibilities, States are seeking new ways to monitor and enforce truck size and weight regulations to safely manage the transportation of goods by commercial vehicles.

Known limitations of fixed weigh station-based screening and enforcement activities (e.g., ability of overweight vehicles to use routes around the fixed sites to bypass enforcement resources, high-deployment and ongoing maintenance costs, required physical footprint of a fixed facility, land costs) also provide strong motivation for States to consider new approaches to roadside compliance verification and enforcement. To address these and other issues, States are increasingly turning to "virtual weigh stations" (VWS). A VWS provides screening and monitoring capabilities like that found at fixed weigh stations but does not require continuous human staffing and can be deployed at a lower cost than a fixed site. Numerous States already have deployed virtual weigh stations as part of their roadside enforcement programs.

For this project, the Federal Highway Administration's (FHWA) Office of Freight Management and Operations and the Federal Motor Carrier Safety Administration's (FMCSA) Technology Division deployed two VWS 'Model Sites' that meet the specifications contained in the Architecture for Electronic Permitting (e-Permit)/Virtual Weigh Stations.(1) The sites are located on U.S. 25 in Laurel County, Kentucky and on Interstate 26 in Unicoi County, Tennessee. These sites are intended to demonstrate the functionality and viability of VWS and advance the "Smart Roadside Initiative" (SRI) concept developed by FHWA and FMCSA.(2)

The project was completed in two Phases. Phase I, Planning and Build-Up, began in the fall of 2013 and was completed in July 2014. Phase II, Implementation, began in August 2014. Site installation and performance testing was completed in early 2016. The final portion of Phase II, Site Maintenance and Support, will extend through April 30, 2019.

The purpose of this document is to provide an overview of the project, highlight project successes, issues, and resolutions, and demonstrate how each deployment was successfully implemented throughout all Phases of the project.

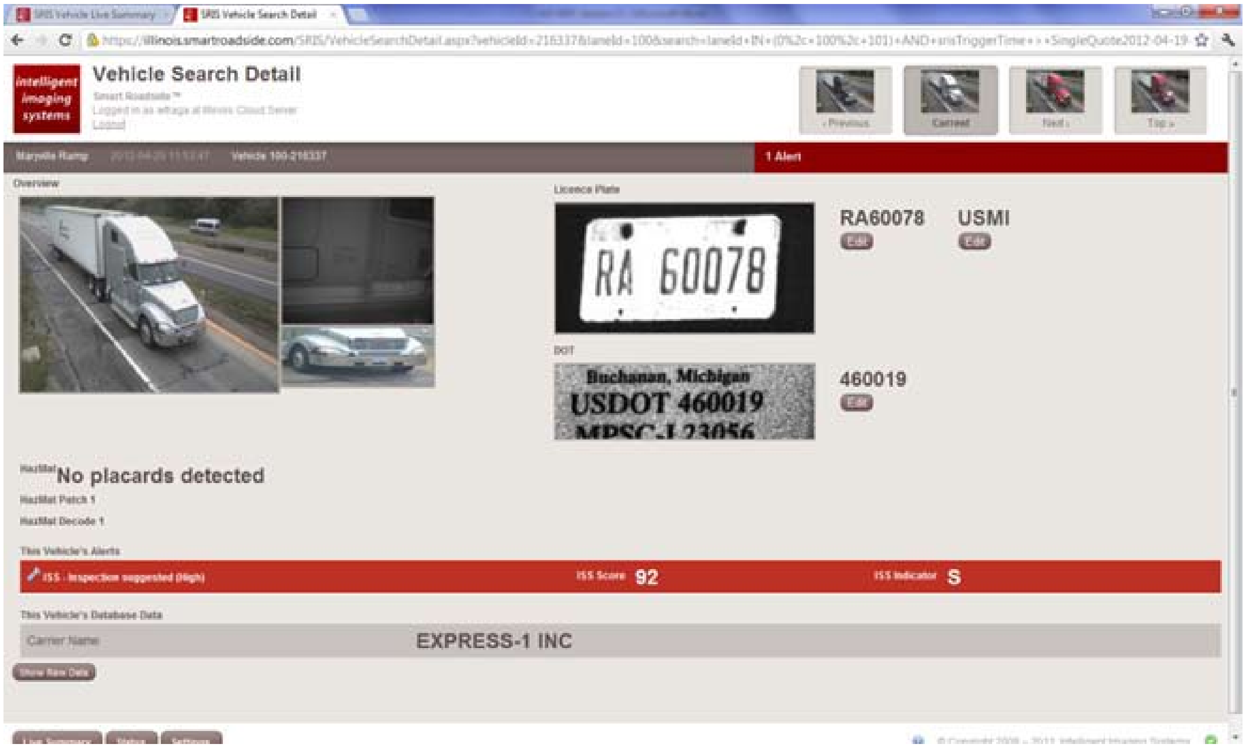
The content in this summary report (task 6) largely follows the Task structure used to develop this project and is organized as follows:

- **Chapter 2 (Task 1).** Provides a brief overview of the project plan and project management approach.
- **Chapter 3 (Task 2).** Includes an inventory and assessment of current conditions at each of the target sites.
- **Chapter 4 (Task 3).** Describes the test and implementation plan for the model sites.
- **Chapter 5 (Task 4).** Summarizes site construction and implementation.

- **Chapter 6 (Task 5).** Analyzes site performance and provides recommendations and responses to an independent analysis conducted by Oakridge National Laboratories (ORNL).

- **Chapter 7 (Task 7).** Explains the continuing support for this project and next steps.

References to documents with additional information developed under each of the Tasks are included at the end of relevant chapters. These documents are available upon request from FHWA.



Licence Plate: RA60078 USMI

DOT: 460019

HazMat No placards detected

HazMat Patch 1

HazMat Decode 1

This Vehicle's Alerts

ISS - Inspection suggested (High) ISS Score 92 ISS Indicator S

This Vehicle's Database Data

Carrier Name EXPRESS-1 INC

Figure 1. Photo. Vehicle search detail screen.
(Source: FHWA)

CHAPTER 2. PROJECT PLAN (TASK 1)

For a project of this scale, developing a project management process was an essential component in project success. The study team consisted of the following public sector agencies:

- Federal Highway Administration (FHWA) Office of Freight.
- Federal Motor Carrier Safety Administration (FMCSA).
- Oak Ridge National Laboratories.
- Kentucky DOT and State Police.
- Tennessee DOT and Highway Patrol.

Task 1 detailed the study team's approach to processes, methods, and procedures in the following areas:

- Human Resources Management.
- Time and Scope Management.
- Cost Management.
- Quality Management.
- Communications Management.
- Risk Management.

Figure 2 below shows the Work Breakdown Structure (WBS) for the project. The diagram illustrates how each sub-task fits within the overall project Scope and shows how prior Tasks were built upon to complete later assignments.

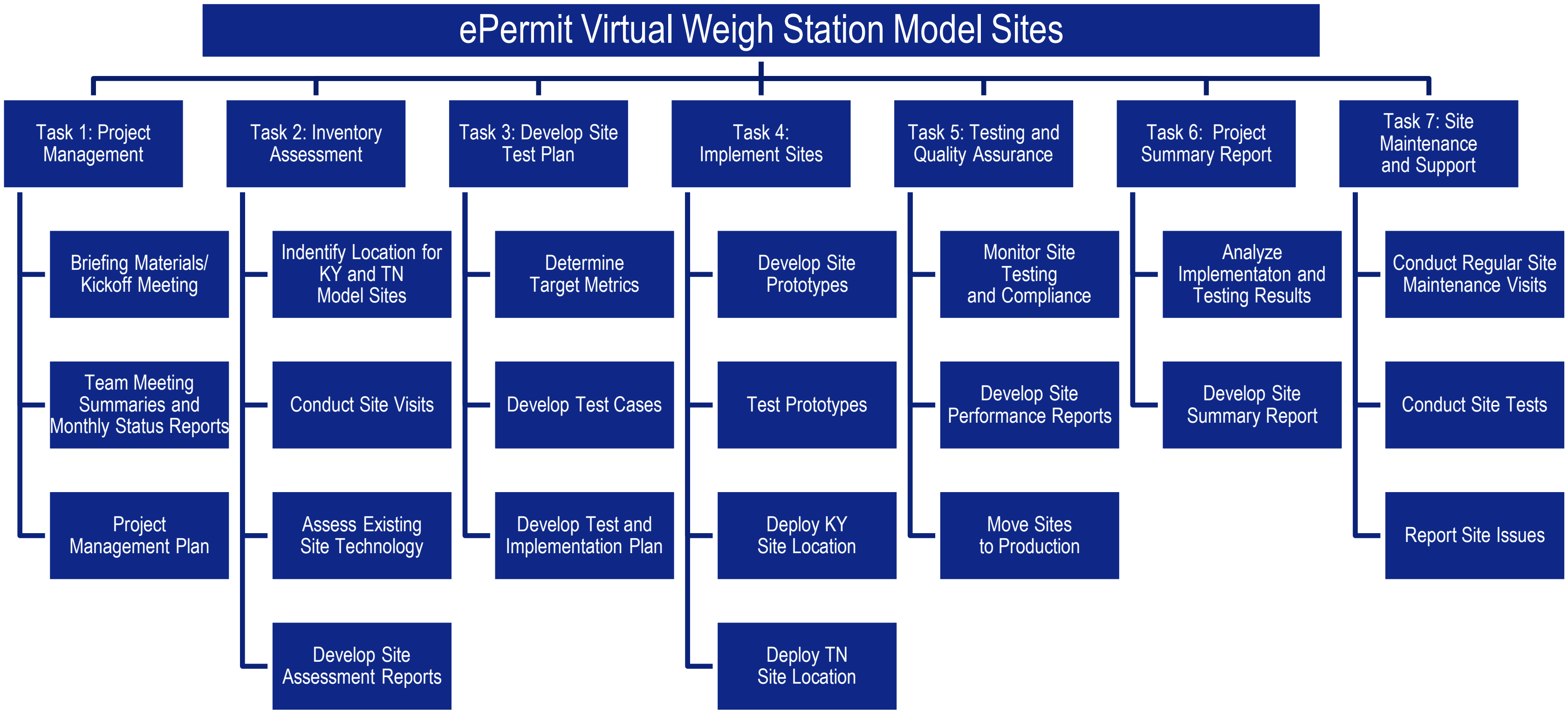


Figure 2. Chart. Work breakdown schedule.
(Source: FHWA)

CHAPTER 3. INVENTORY AND ASSESSMENT OF TARGET SITES (TASK 2)

This chapter provides a Site Report for the two model sites, one in Laurel County, KY, the other in Unicoi County, TN. The purpose of the Site Reports was to inventory, analyze, and assess the existing roadside technology present at each weigh station, with an eye to identifying what additional equipment is required to successfully conduct the e-Permit/VWS test at both sites. The results of the assessment informed the Test Plan and helped the team properly requisition a VWS configuration. The remainder of this chapter consists of two sections. The first summarizes the Site Report for the Laurel County, KY site. The second summarizes the Site Report for the Unicoi County, TN site.

KENTUCKY

Location

Figure 3 highlights the location of the Kentucky VWS (see the marker labeled "Laurel County VWS" on U.S. 25). The site is in Laurel County just north of the following address:

8325 South U.S. 25
Corbin, Kentucky

U.S. 25 parallels I-75 to the east and is a known commercial vehicle bypass route around existing northbound weigh scales on I-75. U.S. 25 passes by two area schools and multiple residential areas, raising safety concerns due to high truck volume.

The intent of locating the VWS at this site is to identify Kentucky-bound (northbound) truck traffic attempting to bypass the I-75 northbound scales.

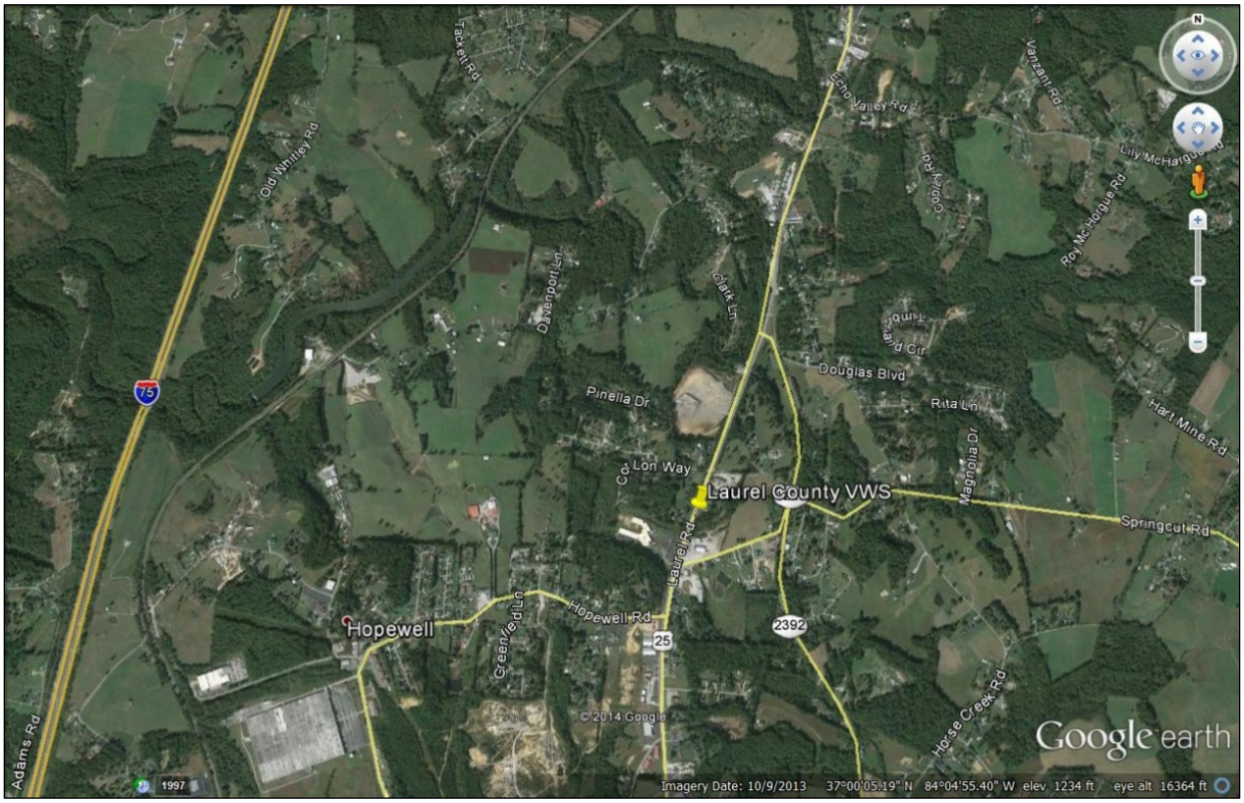


Figure 3. Photo. Location of Laurel County virtual weigh station.
(Source: Google Earth)[1]

Existing Conditions

U.S. 25 is a two-lane road with a 7-foot, non-raised median and a 10-foot shoulder in the northbound direction. A guardrail is present next to this shoulder. The narrowness of the shoulder and the presence of the guardrail will require enforcement officers to escort trucks to a safe pull-off area somewhere downstream of the VWS.

There is a mix of commercial and noncommercial vehicles at this site, though most traffic appears to be noncommercial. The site did not have any existing VWS equipment to evaluate during the site visit.

Proposed Site Improvements

Since there is no existing roadside equipment at the Laurel County site, this project required installation of a complete system. The technology and hardware to be deployed includes:

- Smart Roadside cabinet with all electronics.
- Automated License Plate Reader (ALPR).

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- Automated U.S. Department of Transportation (USDOT) Number Reader (AUNR).
- Overview Camera (OVC).
- Weigh-in-motion (WIM).

The preference for communications was to run a hard-wired connection into the roadside cabinet. The intent is to have officers in mobile units access the system using laptops with cellular data modems. From the laptop, the officers will be able to view a live summary of all commercial vehicles as they move northbound along U.S. 25.

Figure 4 presents the proposed layout of the loops and roadside equipment. The VWS envisioned for the Kentucky test site would involve WIM and portable scales for vehicle measurement; USDOT number and license plate readers for vehicle identification; and screening based on CVIEW/SAFER/ITD (or an equivalent Kentucky system) combined with Web portal access for mobile enforcement units. For the WIM, further testing was recommended to test pavement roughness against appropriate standards due to current pavement conditions that could impact the accuracy of WIM readings. The site will not utilize transponders for vehicle identification.

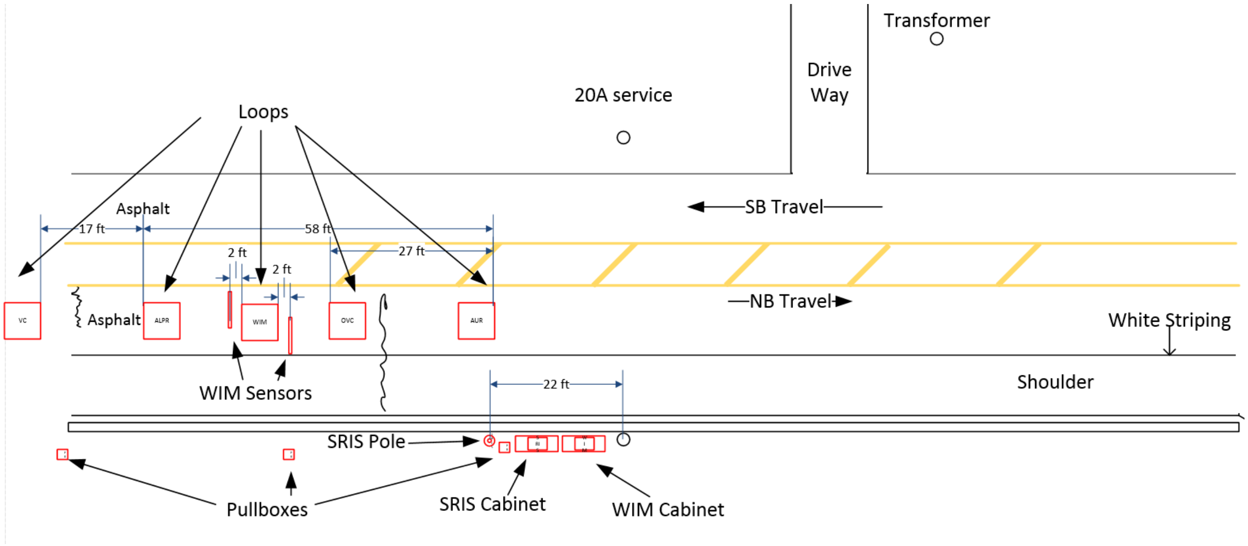

Figure 4. Diagram. Proposed layout for roadside screening equipment.
(Source: FHWA)

The *Electronic Permitting/Virtual Weigh Station Architecture* identified several “best practice” technologies based on a review of commercial motor vehicle (CMV) inspection sites around the country.(3) Table 1 compares these best practices to the proposed solutions at the Laurel County VWS.

Table 1. Relationship of proposed Laurel County systems to “best practice” technologies.

“Best Practice” Technologies	Laurel County Site Technology/Functionality
Mainline or ramp-based WIM.	Mainline WIM.
Multiple CMV identification technologies: • 915 MHz transponder-based. • USDOT number reader. • License plate reader. • **Future:** Universal Truck ID.	USDOT number reader, license plate reader, overhead camera for visual verification.
Local computing resources to execute screening processes and access databases.	Hard-wired Internet connection through roadside cabinet will allow for real-time screening/display on enforcement staff’s laptops.
Connectivity to State back-office systems.	Dependent on Kentucky installing appropriate hardware and security protocols.
Connectivity to databases in other States.	Dependent on those States providing access to their systems.
Automatically generated alerts for enforcement personnel.	SRIS system accessible through Web portal on officers’ laptops—will provide screening decisions in real time.
In-cab notifications for transponder-equipped vehicles.	N/A—CMVs will be directed to safe pull-off area by mobile enforcement units.
Fixed or dynamic message signs for non-equipped trucks.	N/A—CMVs will be directed to safe pull-off area by mobile enforcement units.
Future: Inputs from Wireless Roadside Inspection Technologies.	N/A—Functionality is not yet available but there are no obvious interoperability issues.

TENNEESSEE

Location

The Tennessee VWS is located on Interstate 26 at milepost 0 in Unicoi County, south of Johnson City in eastern Tennessee (see marker labeled “Unicoi” in figure 5). The intent of locating the VWS at this site is to monitor the northbound traffic coming into Tennessee from North Carolina.

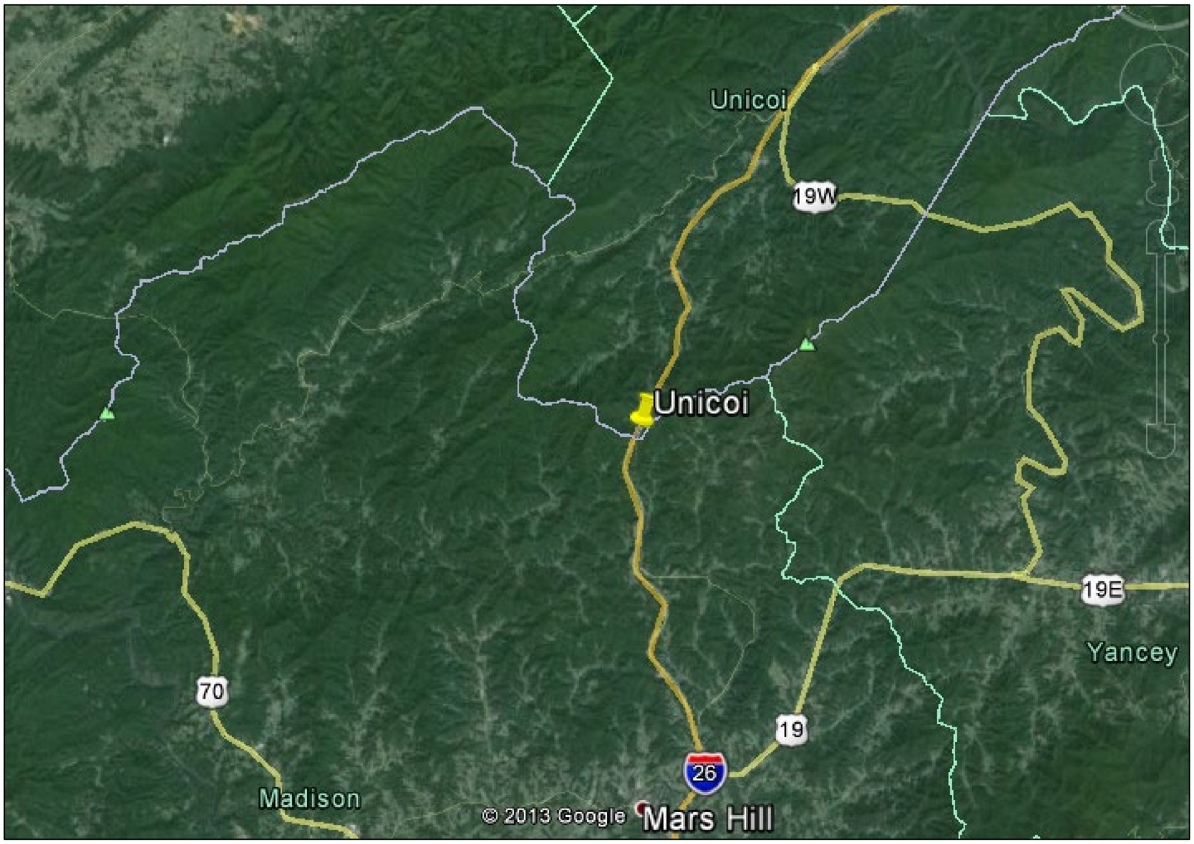

Figure 5. Photo. Location of Unicoi County virtual weigh station.
(Source: Google Earth)[2]

Existing Conditions

The proposed VWS site currently has a ramp and parking area for trucks. Trucks are directed by overhead signs on I-26 to pull off the mainline as they approach the site. After entering the ramp, they pass over the existing (nonfunctional) WIM sensors. From there, they may continue through the site and rejoin I-26 or park in provided truck spaces on site, for example if a mobile enforcement unit determines that an inspection is required. This site is not typically staffed and enforcement was not being conducted during the site visit. This means that commercial vehicle traffic from North Carolina can pass through Tennessee using I-26 and never pass by a functioning weigh scale.

The ramp appears to be in good condition except for three cracks. The ramp is relatively low speed and trucks are slowing down as they approach the entry of the site (observed speed of approximately 35 miles per hour). However, the condition of the VWS entry ramp (cracks and an abrupt transition from asphalt to concrete) may impact the accuracy of WIM readings at the Unicoi VWS. This may be an issue if road conditions at the site do not meet American Society for Testing and Materials (ASTM) standards for smoothness.

Figure 6 provides a view of the ramp looking northward.

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Figure 6. Photo. Tennessee virtual weigh station tamp overview.
(Source: FHWA)

The current state of the WIM cabinet and equipment could not be evaluated and it is not known if the equipment works or not. The site also has two equipment poles, each with a camera. One of the poles had what appeared to be a Wi-Fi antenna.

Proposed Site Improvements

Even though the site has existing equipment, it is not recommended that this equipment be reused. The WIM cabinet was not powered and had clear signs of missing equipment. The existing WIM system has not been operational for some time and the team was unable to determine the functionality of current equipment.

The VWS envisioned for the Unicoi test site would involve ramp WIM and portable scales for vehicle measurement; USDOT number and license plate readers for vehicle identification with visual verification provided by way of overhead cameras; and screening based on CVIEW/ SAFER/ITD (or an equivalent Tennessee system) using screening algorithms combined with

Web portal access for mobile enforcement units. It will not utilize transponders for CMV identification. Drivers will be directed to pull into the site by existing overhead signs on the mainline and will be guided on the site by enforcement personnel.

Table 2 compares "best practice" technologies to the proposed solutions at the Unicoi VWS.(3)

Table 2. Relationship of proposed Unicoi County systems to "best practice" technologies.

"Best Practice" Technologies	Unicoi Site Technology/Functionality
Mainline or ramp-based WIM	Ramp WIM.
Multiple CMV identification technologies: • 915 MHz transponder-based. • USDOT number reader. • License plate reader. • **Future:** Universal Truck ID.	USDOT number reader, license plate reader, overhead camera for visual verification.
Local computing resources to execute screening processes and access databases.	Hard-wired Internet connection through roadside cabinet will allow for real-time screening/display on enforcement staff's laptops.
Connectivity to State back-office systems.	Dependent on Tennessee installing appropriate hardware and security protocols.
Connectivity to databases in other States.	Dependent on those States providing access to their systems.
Automatically generated alerts for enforcement personnel.	Smart Roadside Initiative (SRI) System accessible through web portal on officers' laptops—will provide screening decisions in real time.
In-cab notifications for transponder-equipped vehicles.	N/A—CMVs will be directed to enter site by way of overhead signs.
Fixed or dynamic message signs for non-equipped trucks.	Fixed signs.
Future: Inputs from Wireless Roadside Inspection Technologies.	N/A—Functionality is not yet available but there are no obvious interoperability issues.

CHAPTER 4. TEST PLAN (TASK 3)

This chapter summarizes the Test and Implementation Plan for the model sites in Kentucky and Tennessee. The purpose of the Test and Implementation Plan was to outline the test objectives, approach, key specifications, test metrics, and operational testing plan for this project. By documenting these items in advance, this document ensured a successful test that met the needs of all stakeholders and placed the Laurel County, KY and Unicoi County, TN sites in service as virtual weigh stations (VWS) for the duration of the test.

The goal of the operational tests was to successfully demonstrate the design, planning, and deployment of the two e-Permit/VWS 'Model Sites' and show that they are fully responsive to the functionality outlined in the Architecture for Electronic Permitting (e-Permit)/Virtual Weigh Stations developed by USDOT and published in 2011. The sites will be compatible with the Federal Motor Carrier Safety Administration (FMCSA) Commercial Motor Vehicle Technical Corridor (CMVRTC) and the Smart Roadside Initiative (SRI). Proposed functionality includes the ability to:

- Obtain unique identifying information for CMVs passing by the sites.
- Identify CMVs by cross-referencing the identifying information with relevant State and Federal databases, such as the Innovative Technology Deployment (ITD) Program Commercial Vehicle Information Exchange Window (CVIEW).
- Collect vehicle measurements, including weight, axle spacings, truck classification, and length while the truck is in motion.
- Correlate vehicle measurements to the trucks identified.
- Conduct automated screening based on agency business rules.
- Alert enforcement staff of any suspected violators, based on screening results.
- Capture enforcement actions taken (e.g., citations, out of service orders).
- Update State back office systems (e.g., CVIEW) as required.

Additionally, the Laurel County, KY site will be able to trigger a Wireless Roadside Inspection.

TEST ENVIRONMENT AND APPROACH

The project team provided all necessary hardware for both sites (e.g., ALPR, AUNR, cameras, WIM, and Smart Roadside cabinet with all electronics) and both the Kentucky and Tennessee sites utilized electronic screening system software to automatically identify and flag potentially unsafe commercial vehicles for advanced roadside screening.

Enforcement staff will be able to connect to the system and view vehicle details in real-time. At the Tennessee site, this will consist of enforcement officers parked at the Unicoi County VWS site (which has a pull-in area for trucks) who will view a live feed on their laptops via a cellular modem. In Kentucky, screening data will be automatically transmitted to the commercial vehicle inspection station located on I-75 in Laurel. Staff at the station will be able to take enforcement action for commercial vehicles using US 25 to bypass the northbound inspection station.

Testing began once several entry criteria were met, including USDOT approval of the Test and Implementation Plan, installation and functionality of all hardware and software at both sites, confirmation that data is being transmitted to appropriate State systems and enforcement staff, successful installation, calibration, and functioning of the WIM, and confirmation that all metrics were being measured and provided for test and evaluation purposes. Testing was considered complete when all equipment was active and functioning properly for a period of four weeks. As noted above, the Kentucky and Tennessee e-permit/VWS deployments were fully compatible with the features/functionality described in the Electronic Permitting/Virtual Weigh Station Architecture.

TEST MANAGEMENT

To manage the operational testing, the project team employed four main strategies:

- Engage stakeholders throughout the process, including pre-deployment testing of the VWS functions to ensure the system met user needs.
- Hold user training sessions for both sites to walk staff through software applications.
- Detect reporting, tracking, and resolution during the test.
- Monitor test participants' use of the applications during the test, and taking corrective action if needed to boost participation.

TEST METRICS

Table 3 below shows all the systems implemented at the Laurel County, Kentucky and Unicoi County, Tennessee sites and the respective metrics from each source.(1)

Table 3. e-Permit/virtual weigh station architecture metrics and verification.

Source	Metric	Implemented
WIM	Gross vehicle weight (GVW)	Yes
	Total vehicle length	No
	Number of axles	Yes
	Individual axle weights	Yes
	Individual axle spacings	Yes
Transponder	Transponder ID	N/A
	VIN	N/A
PRISM	Vehicle license plate	Yes
	Vehicle license plate issuing jurisdiction	Yes
	Vehicle PRISM target file indicator	Yes
	Vehicle carrier ID number	Yes
	VIN	Yes
	Carrier ID number	Yes
	Carrier name	Yes
	Carrier PRISM indicator	Yes
	Carrier MCSIP level	Yes
	Carrier MCSIP date	Yes
Safety Data (from carrier/vehicle systems)	Carrier ID number	N/A
	Driver's license number and State	N/A
	VIN	N/A
	Shipping document ID	N/A
	Tire measures	N/A
	Vehicle position	N/A
	Weight	N/A
	Lighting status	N/A
	Safety belt status	N/A
	EOBR data	N/A

Table 3. e-Permit/virtual weigh station architecture metrics and verification (continuation).

Source	Metric	Implemented
CVIEW/SAFER	Carrier ID number	Yes
	Carrier name	Yes
	Carrier DBA name	No
	Carrier safety rating	No
	Carrier IRP account number	Yes
	Carrier IRP status	Yes
	Carrier Safestat category	Yes
	Carrier liability insurance status	Yes
	Carrier UCR registration status	No
	Carrier IFTA account number	Yes
	Carrier IFTA status	Yes
	Total number of inspections (24 months)	No
	Number of carrier OOS inspections	Yes
	Number of vehicle inspections	No
	Number of OOS vehicle inspections	No
	Number of driver inspections	No
	Number of OOS driver inspections	No
	Number of hazmat inspections	No
	Number of OOS hazmat inspections	No
	VIN	Yes
	Vehicle license plate number	Yes
	Vehicle license plate issuing jurisdiction	Yes
	Vehicle registration status	Yes
	Vehicles carrier responsible for safety	Yes
	Vehicle IRP base State	Yes

Table 3. e-Permit/virtual weigh station architecture metrics and verification (continuation).

Source	Metric	Implemented
State/Local Permits	License plate	No
	Vehicle permit type	No
	Vehicle permit number	No
	Vehicle permit issuing authority	No
	Vehicle permitted weight	No
	Vehicle permitted dimensions	No
	Vehicle permit indicator	No
	Vehicle permit validity period	No
	Vehicle permit status	No
	Vehicle permit restrictions	No
	Vehicle permitted route	No
	Carrier ID number	No
Vehicle Dimensional Measurement (VDIM)	Vehicle dimensions (length, width, and/or height)	N/A

CHAPTER 5. SITE DEPLOYMENT AND IMPLEMENTATION (TASK 4)

The project received permission from FHWA to begin Phase II, Implementation in August, 2015. Necessary hardware and software were installed on U.S. 25 in Laurel County, Kentucky August 19, 2015 and August 24, 2015 and at the Unicoi County, Tennessee site on I-26 between September 21, 2015 and October 1, 2015.

Figure 7. Photo. Laurel County, Tennessee virtual weigh station installation.
(Source: FHWA)

CHAPTER 6. SITE PERFORMANCE (TASK 5)

Following installation and calibration, a site performance review commenced. This chapter summarizes the test results and metrics collected.

Each site utilized the Smart Roadside Inspection System (SRIS) as an automated tool to assist enforcement officers in screening commercial vehicles. The system consists of two subsystems:

- License plate reader.
- USDOT number reader.

The license plate reader and USDOT reader subsystems were evaluated over a period of several days and various weather conditions at the Laurel County, Kentucky and Unicoi County, Tennessee sites. As previously identified, the Kentucky site screens commercial motor vehicles (CMV) on a highway with mobile enforcement monitoring from off-site. The Tennessee site screens CMVs on a ramp with mobile enforcement present on-site to conduct enforcement activities. Overall system performance was measured using an identification rate by combining the performance of the license plate reader and USDOT reader and evaluating how often the system can capture at least one identifying piece of information on the vehicle correctly.

This initial system performance testing was supplemented by a separate test conducted by Oakridge National Laboratories (ORNL).

The remainder of this chapter consists of three sections. The first describes the system features and functionality tested by the project team. The second provides the team's system performance summary at both sites. The third details the subsequent performance test conducted by ORNL, their recommendations, and the team's response to those recommendations.

FEATURES AND FUNCTIONALITY TESTED

Table 4 below identifies the key site processes/functionality, how the functionality was tested, and if the functionality was satisfied during the test. It is based on a project team assessment of functionality found in USDOT e-permit/Virtual Weigh Station Architecture, version 1.2, August 18, 2011.(1)

Table 4. Virtual weigh station functionality assessment.

e-Permit/ VWS Process/ Functionality	Description	How Functionality Will be Satisfied	Compatibility with National ITS Architecture	How functionality has been satisfied
Obtain identifying information.	Automatically capture commercial vehicle identifier(s), e.g., license plate numbers.	ALPR and AUNR will capture license plate and USDOT numbers and convert to digital character strings.	'Identification information' flow of CVO03 and CVO06.	The ALPR and AUNR have been confirmed to capture license plate and USDOT numbers and convert to digital character strings.
Identify vehicle.	Cross-reference identifying information with relevant databases to identify truck and carrier.	License plate/USDOT numbers will be referenced to appropriate databases (e.g., CVIEW) which will return truck and carrier information.	'Identification information' flow of CVO03 and CVO06.	The license plate/ USDOT numbers have been confirmed to reference appropriate databases, returning truck and carrier information.
Collect measurement data.	Automatically capture commercial vehicle weight and dimensions via on-site sensors.	WIM will measure vehicle weight, length, axle spacings, and class, package the data into a standard message, and forward it to the screening system.	'CVO weight and presence' flow of CVO03 and CVO06.	The WIM has been confirmed to measure vehicle weight, length, axle spacings, and class and the data has been confirmed to have been packaged and forwarded to the screening system.

Table 4. Virtual weigh station functionality assessment (continuation).

e-Permit/ VWS Process/ Functionality	Description	How Functionality Will be Satisfied	Compatibility with National ITS Architecture	How functionality has been satisfied
Correlate vehicle identification and measurement data.	Uses data from the Identify vehicle and Collect measurement data processes to create a Vehicle Transaction Record with identification information and weight measurement data.	SRIS will automatically correlate these data and output a transactional record for screening.	'Identification information' and 'CVO weight and presence' flows of CVO03 and CVO06.	SRIS has been confirmed to automatically correlate the identification and measurement data, outputting a transactional record for screening.
Conduct screening.	Automatic querying of State back office systems against preset business rules and generation of alerts to enforcement staff.	Screening algorithm will perform queries of State databases and screen using rules set by test participants (TN Only—KY will confirm data in the Kentucky Assistive Technology Service (KATS) Network).	'Roadside electronic screening' and 'Roadside WIM' equipment packages of CVO03 and CVO06.	SRIS has been confirmed to perform queries of State databases and screen using rules set by test participants in TN. In KY the project team provided access to the vehicle data and (KATS) performs the screening using rules set by test participants.
Alert enforcement.	"Push" alerts provided to enforcement staff to notify them of suspected violations.	Users can configure SRIS software to provide visual, audio, or other alarms of trucks flagged for further scrutiny.	'Information on violators' flow of CVO03.	SRIS software has been confirmed to provide visual, audio or other alarms of trucks flagged for further scrutiny.

Table 4. Virtual weigh station functionality assessment (continuation).

e-Permit/ VWS Process/ Functionality	Description	How Functionality Will be Satisfied	Compatibility with National ITS Architecture	How functionality has been satisfied
Direct CMV action.	Processes for notifying drivers of screening results and/or directing them to a location for further assessment.	**Kentucky**—Screening data will be monitored by enforcement staff in the I-75 weigh station in Laurel. Staff will be dispatched to intercept CMVs on U.S. 25 as required/available. **Tennessee**—Trucks will pull into the existing facility when it is open and staffed by officers, who can weigh vehicles with portable scales and conduct inspections as needed.	'CVO pass/pull-in message' flow of CVO03.	Direct CMV action has been confirmed through the use of KATS in the I-75 weigh station and staff have intercepted CMVs on U.S. 25 as required/ available.
Capture enforcement action.	Process to create a record of any enforcement action taken for a given Vehicle Transaction Record.	Enforcement personnel will update Vehicle Transaction Records as they do now.	N/A.	This has been confirmed by enforcement personnel updating vehicle transaction records as they do now.
Update central database.	Processes to update the State back office system with the results of enforcement actions.	Updated Vehicle Transaction Records to be uploaded back to State back office system (e.g., CVIEW).	'Violation notification', 'daily site activity data', 'citation', and 'CV driver record request' flows of CVO03.	N/A—SRIS is a user of the data rather than a creator of the data.

Table 4. Virtual weigh station functionality assessment (continuation).

e-Permit/ VWS Process/ Functionality	Description	How Functionality Will be Satisfied	Compatibility with National ITS Architecture	How functionality has been satisfied
Refresh on premise database.	Obtain a static copy of the State back office system, including CVIEW to allow for near-real time screening.[3]	N/A—Both sites will feature a hard-wired Internet connection into the State system to allow for real-time screening and updating.	'Violation notifications', 'daily site activity data', 'citation', 'CV driver record request', 'safety status information', 'credential information', 'credential status information', and 'CV driver record' flows of CVO03.	N/A—both sites will feature a hard-wired internet connection into the State system to allow for real-time screening and updating.

TEST OVERVIEW

Evaluation Criteria

The evaluation criteria started with the analysis of the camera subsystems and then combines those results to report on the overall identification rate. The camera subsystem analysis is a two-step process that involves collecting data and then reviewing the results and annotating whether the reader achieved the correct decode or if not, why the reader had trouble with that image. A standard annotation has been developed by the technology vendor to assist in consistently measuring system performance. Definitions for these annotations is given in table 5 and

Table 6 for the license plate reader and USDOT reader respectively. A result can only belong to a single category.

Competing systems often include a "Not Machine Readable" category to capture the reason for a failed decode relating to poor image quality, sun and shadow related effects, and exotic or very difficult to read fonts. We include all events that would normally fall under this category in our performance analysis and assign them as either "Incorrect" reads or "No Reads" because the system is expected to always capture high-quality images suitable for optical character. In addition, the system is expected to read all legal USDOT fonts and license plate fonts and therefore fonts that were exotic or difficult for a machine to read (but not a human) were included in the analysis. This provides the most accurate representation of the performance of each system and an accurate reflection of system performance.

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[3] Alternately, a direct connection to the State back office system may be used if the site has high-speed connectivity to that system.

Table 5. Result definitions for license plate reader.

	Definition	Code
Correct	All the digits on the license plate matched the decode result perfectly (no added digits, no missed digits, and no incorrect digits).	CO
Incorrect	Not all of the digits on the license plate matched the decode result (one or more digits added, missed, and/or incorrect).	IN
Not Read	System did not locate a visually verified front license plate.	NR
Not a Commercial Vehicle	The vehicle was not a commercial vehicle (FHWA class 1, 2, 3, and 4), e.g., recreational vehicle, car, SUV, van, pickup truck.	NCV
No License Plate	The commercial vehicle did not have a front license plate.	NLP
Excluded	A damaged, highly bent, very dirty, chipped, or occluded license plate that was the cause of a failed read. This category includes unexpected driver behavior, including when the vehicle was outside of the lane markers.	EX

Table 6. Result definitions for U.S. Department of Transportation reader.

	Definition	Code
Correct	All the numbers on the USDOT reader matched the decode result perfectly (no added numbers, no missed numbers, and no incorrect numbers).	CO
Incorrect	Not all of the numbers on the USDOT matched the decode result (one or more numbers added, missed, and/or incorrect).	IN
Not Read	System did not locate a visually verified USDOT number.	NR
Not a Commercial Vehicle	The vehicle was not a commercial vehicle (FHWA class 1, 2, 3, and 4), e.g., recreational vehicle, car, SUV, van, pickup truck.	NCV
No USDOT Number	The commercial vehicle did not have a USDOT number.	NUS
Excluded	A damaged, very dirty, chipped, or occluded USDOT number that was the cause of a failed read. USDOT numbers that did not meet the FHWA standards are placed in this category. This category includes unexpected driver behavior, including when the vehicle was outside of the lane markers.	EX

After annotating each result, the read rate is computed by the equation in figure 8:

$$Read\ Rate = \frac{N_{CO}}{N_{CO} + N_{IN} + N_{NR}}$$

Figure 8. Equation. Read rate.

Where N_{CO}, N_{IN} and N_{NR} denote the number of results labelled with the Correct, Incorrect, and Not Read categories respectively during the time periods of analysis. Therefore, the vehicles with a code of NCV, NLP/NUS or EX are excluded in the computation of read rates. Figure 8 applies to the computation of read rate for both license plate reader and USDOT reader.

The identification rate is a measure of the system's ability to correctly decode either the license plate or USDOT number. The identification rate can be computed directly from the license plate reader and the USDOT reader results and annotations are assigned per table 7.

Table 7. Result definitions for identification rate.

	Definition	**Code**
Correct	Either the license plate was decoded correctly or the USDOT number was decoded correctly or both were decoded correctly.	CO
Not a Commercial Vehicle	The vehicle was not a commercial vehicle (FHWA class 1, 2, 3, and 4), e.g., recreational vehicle, car, SUV, van, pickup truck.	NCV
No Identification	The commercial vehicle had neither a front license plate nor a USDOT number (i.e., the commercial vehicle was labelled as NLP for license plate reader and labelled as NUS for USDOT reader).	NID
Excluded	The commercial vehicle had code of EX for license plate reader and code of NUS or EX for USDOT reader, or had code of EX for USDOT reader and code of NLP or EX for license plate reader.	EX
Incorrect or Not Read	The commercial vehicle was not CO, NID, or EX. In another word, the commercial vehicle had code of IN or NR for license plate reader and non-CO code for USDOT reader, or had code of IN or NR for USDOT reader and non-CO code for license plate reader.	INNR

The identification rate is computed according to figure 9:

$$Identification\ rate = \frac{N_{CO}}{N_{CO} + N_{INNR}}$$

Figure 9. Equation. Identification rate.

Where N_{CO} and N_{INNR} denote the number of results labelled with the Correct, and Incorrect or Not Read, respectively. Vehicles with a code of NCV, NID or EX are excluded in the computation of identification rate.

Test Results

Overall system performance was found to be quite good. The read rate for the license plate reader performed at around 80 percent at both locations, while the USDOT read rate varied from 77.8 percent in Laurel County to 82.2 percent in Unicoi County. The identification rates were 89.4 percent for Laurel Country, KY and 92.7 percent for Unicoi County, TN.

The subsystem read rates and the identification rate, as assessed for two days during October, 2015, is summarized in table 8. Note that a correct identification is based on a correct decoding of either the USDOT number or license plate (or both).

Table 8. Summary of overall system performance.

	License Plate Reader—Read Rate	**USDOT Reader—Read Rate**	**Combined Systems—Identification Rate**
Laurel County, KY	77.4%	77.7%	89.4%
Unicoi County, TN	79.9%	82.2%	92.7%

Kentucky:

Testing at the Laurel County, KY site commenced at 7:00 a.m. on October 18, 2015 and ended at 7:00 a.m. on October 20, 2015. The weather on October 18 was overcast with rain in the late afternoon and evening. The weather on October 19 was a bright and sunny day with no rain. A total of 1,291 vehicles passed the VWS during the time with a length greater than 25 feet.[4] A summary of performance at the site is shown in table 9 below.

Table 9. Laurel County, Kentucky virtual weigh station performance summary.

	License Plate Reader—Read Rate	**USDOT Reader—Read Rate**	**Combined Systems—Identification Rate**
Day	77.0% [1]	78.8% [2]	89.0%
Night	78.4%	74.3%	90.2%
Overall	77.4%	77.7%	89.4%

[1] Sunlight through trees behind the camera affected daytime performance on October 19, 2015.

[2] Rain affected the license plate reader in the late afternoon on October 18, 2015.

The license plate reader performance at Laurel County was found to be weather-dependent. The camera performed best during sunlight but suffered during dark overcast periods. In addition, nighttime rain created a reflective surface on the road that confused the camera. The license plate reader achieved an 88.5 percent identification rate from 7:00 a.m. to 2:00 p.m. on October 18,

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[4] This length was used to filter out most small vehicles and reduce the number of vehicles requiring review

2015 just before the dark weather and rain started highlighting the variability in the performance with respect to the external conditions.

The USDOT reader performance was significantly lower at the Laurel County site compared to Unicoi County because of the sun shining through large trees behind the camera creating complicated shadow patterns across passing trucks for about four hours. An analysis of the USDOT reader during overcast weather on October 18, 2015 revealed that the day performance was significantly higher at an identification rate of 83.6 percent. The USDOT reader performance at Laurel is likely highly dependent on the amount of sunlight and position of the sun at different times of the year. Removing the trees behind the camera would improve the performance of the USDOT reader.

In addition, a small percentage of drivers crossed the center line and this affected both license plate reader and USDOT reader performance. Vehicles that did this were removed from the study.

Tennessee: Data was collected at the Unicoi County, TN site between October 16, 2015 at 2:00 p.m. and October 19, 2015 at 2:00 p.m. local time for a total of 72 hours. A total of 1,268 vehicles were recorded and analyzed during that time.

Site performance at Unicoi is shown in table 10. Overall performance was higher than at the Laurel County, KY site for both the License Plate Reader and USDOT Reader systems, and system performance was much more consistent with respect to weather or time-of-day.

Table 10. Unicoi County, Tennessee virtual weigh station performance summary.

	License Plate Reader—Read Rate	USDOT Reader—Read Rate	Combined Systems—Identification Rate
Day	79.8%	84.5%	94.2%
Night	80.2%	77.5%	89.7%
Overall	79.9%	82.2%	92.7%

OAK RIDGE NATIONAL LABORATORY TESTS

Oak Ridge National Laboratory (ORNL) was tasked by FHWA and FMCSA to conduct an independent evaluation of the reliability and accuracy of the information collected at the Laurel County, KY and Unicoi County, TN sites.

Methodology

ORNL collected data from both sites in January 2016. For each site, the data was divided into two sets and the information used to analyze the reliability and accuracy[5] of the parameters collected. Reliability and accuracy are like the read rate and identification rate metrics used by the study team, though the methodology used to determine scores differed.

The first data set "All Data" was the entire collection of records that was downloaded by ORNL from each site. This information was used to assess the reliability of the system at identifying meaningful information for the parameters under consideration (i.e., USDOT number, license plate jurisdiction and number, and some inferences about number of axles, and vehicle weight). Because of the large dataset (thousands of observations), the assessment of the reliability of these parameters has a strong statistical significance.

Reliability ***R*** (in percent) is defined in figure 10 as:

$$R = \frac{N_v}{N_t} \times 100$$

Figure 10. Equation. Reliability.

Where N_t is the total number of observations (i.e., data sample size) and N_v is the total number of valid observations (i.e., the total number of observations that contain meaningful—true or false—information). Notice that always $N_v <= N_t$.

Even in cases were no direct or independent measurements were made, system reliability boundaries could be determined. For example, given a set of records where the system provides the number of axles of the vehicles, records which show vehicles with 0 (zero) or 1 (one) axle can be counted as having unreliable (and inaccurate) information. In the same way, vehicles weighing more than 150,000 lb. as determined by the system can be counted as having unreliable and inaccurate information.

However, when the parameters are within logical values (e.g., number of axles between 2 and 11, or vehicle weight between 25,000 lb. and 80,000 lb.), it is necessary to use external methods to assess the validity of these parameters. This led to the creation of a second data set, "Selected Data."

Starting from the oldest record, the analyst selected one record randomly and by using the images collected by the system determined the outdoor conditions in terms of light (daytime or nighttime) and weather condition (clear, rainy, etc.). Then thirty or more consecutive observations were selected and added to the second set. After that, another record was selected at random and the outdoor conditions verified. If a subset with these conditions had not been yet selected, thirty or more consecutive observations were chosen and added to the second set. If the

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[5] For more detailed definitions of "reliability" and "accuracy" refer to Section 2.1 of "Reliability and Accuracy of Laurel County, Kentucky and Unicoi County, Tennessee Virtual Weigh Stations: Final Report."

outdoor conditions were already included in the second set, then the analyst selected a different record at random and used the same methodology to determine whether to select data for the second subset. The second data set—"Selected Data"—for each site consisted of about two hundred observations that were used to visually compare the information contained in the images to the information extracted from these images by the system.

Other parameters, such as vehicle total weight, axle weight, and axle spacing required direct measurements of those parameters. The Tennessee Highway Patrol (THP) randomly inspected selected vehicles that traveled by the system at the Unicoi County site, using portable scales (calibrated regularly and certified to have at most +/-3% error) to weigh each axle of the inspected vehicle, and measuring tapes to determine the axle spacing.[6] Electronic forms were provided by ORNL so the officers could enter the information collected in the field as well as the information provided by the system for the same vehicle.

ORNL used the "Selected Data" set to compare the values of the parameters against the information that could be seen on the images captured by the system for USDOT number and license plate information (as well as other parameters such as number of axles, for example). Because of this, reliability measures are presented in some of the results two ways.

The "Selected Data" set only was used to determine system accuracy. Because in some cases it was not possible to visually corroborate some of the parameters provided by the deployed system using the captured images (e.g., in some cases it was not possible to visually determine the jurisdiction shown on a license plate due to low the quality of the image) two types of accuracy observations were defined: 1) Y* defined as the number of observations for which it is not possible to corroborate the information provided by the system (e.g., impossible to visually determine the License Plate Jurisdiction). The "benefit of the doubt" is given to the system and the observation is labeled as accurate; and 2) Y defined as the number of observations for which it is possible to visually corroborate the information provided by the system and the information is found to be accurate.

The ORNL report used two definitions of accuracy. Absolute accuracy A_a (in percent) is defined as shown in figure 11.

$$A_a = \frac{N_{ta}}{N_t} \times 100$$

Figure 11. Equation. Absolute accuracy.

Where N_t is the total number of observations (i.e., data sample size) and N_{ta} is the total number of accurate observations (i.e., the total number of observations that contain information for which accuracy can be corroborated). Notice that always $N_{ta} <= N_v <= N_t$.

Relative accuracy A_r (in percent) is defined as shown in figure 12. Notice that $A_a <= A_r$.

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[6] A similar analysis was not conducted at Laurel County, KY due to safety concerns.

$$A_r = \frac{N_{ta}}{N_v} \times 100$$

Figure 12. Equation. Relative accuracy.

Results

The initial assessment found that the Unicoi County, TN site was working reasonably well but that the Laurel County, KY site was not functioning properly. For example, at the Laurel County site, images of the side of some vehicles were sometimes mixed with images of the license plates of different vehicles. At times, the system was triggering even with passenger cars. The January 2016 data from Unicoi County was analyzed as part of this review. For Laurel County, ORNL discarded the January 2016 data and instead analyzed data from March-April 2016 after the system was modified.[7]

Laurel County, KY: To test accuracy, 214 observations (Selected Data) were manually corroborated from a pool of 16,176 observations (All Data) collected during the time from March 19, 2016 to April 18, 2016.

For the license plate jurisdiction measure, accuracy was difficult to determine. The analyst could clearly see the jurisdiction which also matched with what the system automatically provided in just 121 cases out of 214 cases. In an additional 30 cases, the analyst could not definitively determine that the system was wrong, so those records were evaluated as accurate/non-corroborated (Y* = 30). This table (and all other tables in this section) contains two measures of accuracy: the absolute accuracy and the relative accuracy. The former is computed using as the denominator all the observation, while the latter only used the number of reliable information. Both measures are useful, but the second gives an idea of accuracy in cases where it is possible to filter out unreliable information. Table 11 below shows the results.

Table 11. License jurisdiction reliability and accuracy (Laurel County, Kentucky).

Data Set	Measure	Count	Percentage
Selected Data	Reliability	184 (214)	85.98%
Selected Data	Absolute Accuracy (Y*+Y)	151 (214)	70.56%
Selected Data	Relative Accuracy (Y*+Y)	151 (184)	82.07%
Selected Data	Absolute Accuracy (Y)	121 (214)	56.54%
Selected Data	Relative Accuracy (Y)	121 (184)	65.76%
All Data	Reliability	14,340 (16,176)	88.65%

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[7] Raw data used in the analysis is found in Appendixes B and C of "Reliability and Accuracy of Laurel County, Kentucky and Unicoi County, Tennessee Virtual Weigh Stations: Final Report."

While the reliability (meaningful information could be identified) of this parameter is relatively high, accuracy (correctness) of the information was very low. Of all the observations, between half and slightly over two thirds presented an accurate value for the License Jurisdiction parameter. System accuracy was the worst during clear nights.

The License Plate Number parameter had a reliability of 100 percent for the selected data and 99.4 percent for the entire dataset for the Laurel County site (i.e., the system generated some NA or Null values for this parameter). The absolute accuracy was 69 percent for the selected data and slightly lower (i.e., 68 percent) for the entire dataset analyzed.

For the USDOT number parameter, reliability was slightly less than 84 percent while accuracy was around 70 percent. This system was most reliable during the day in light rain and the highest accuracy was achieved during clear nights.

ORNL also analyzed the combined reliability and accuracy of license plate jurisdiction and number and the USDOT number, which are required for the identification of a vehicle. Table 12 shows that the reliability and accuracy of the combination of these three parameters is lower than any one parameter taken separately. While the reliability was just about 70 percent, the accuracy of the combination could be as low as 30 percent (absolute) 41 percent (relative).

Table 12. License plate information and U.S. Department of Transportation number reliability and accuracy (Laurel County, Kentucky).

Data Set	Measure	Count	Percentage
Selected Data	Reliability	157 (214)	73.36%
Selected Data	Absolute Accuracy (Y*+Y)	79 (214)	36.92%
Selected Data	Relative Accuracy (Y*+Y)	79 (157)	50.32%
Selected Data	Absolute Accuracy (Y)	64 (214)	29.91%
Selected Data	Relative Accuracy (Y)	64 (157)	40.76%
All Data	Reliability	11,273 (16,176)	69.69%

The deployed system had a high reliability at assessing the number of axles that a vehicle had, about 97 percent. The accuracy was slightly lower (as low as 92.5 percent), with the worst outdoor conditions for both reliability and accuracy being nighttime clear conditions. Comparing the number of axles versus the number of axles with an identified weight (a value other than “0” or “NULL”) also showed high reliability (94 percent with Selected Data, 98.6 percent with All Data) and accuracy (96 percent) values.

Unicoi County, TN: For the Unicoi County site, 181 observations (Selected Data) were manually corroborated from a pool of 7,509 observations (All Data) collected from January 4, 2016 to January 31, 2016. The Selected Data was comprised of 35 daytime-cloudy, 36 daytime-partly cloudy, 40 daytime-sunny, 35 daytime-clear, and 35 nighttime-rain observations.

For the license jurisdiction analysis, in only 87 cases out of 181 the analyst could clearly see the jurisdiction which also matched with what the system automatically provided. In an additional 42 cases, the analyst could not definitively determine that the system was wrong, so those records were evaluated as accurate/non-corroborated (Y* = 42). While the reliability of this parameter is relatively high, the accuracy was very low. Of all the observations, between half and slightly over two thirds presented an accurate value for the License Jurisdiction parameter. Rainy nights were the worst-case weather condition for both reliability and accuracy measurements.

The license plate reader performed significantly better at the Unicoi County site than at the Laurel County site. As shown in table 13, the license plate number metric had a reliability of 100 percent for both the selected data and the entire dataset for the Unicoi County site (i.e., the system never generated a NA or a Null). The accuracy was 77.4 percent (note, the absolute and relative accuracy measures were the same since the reliability was 100 percent). For this parameter, and similarly to License Plate Jurisdiction, the best outdoor conditions were daytime partly cloudy. However, the worst conditions were found during a sunny day, possibly due to reflection or the low number of observations conducted as part of this test.

Table 13. License plate number reliability and accuracy (Unicoi County, Tennessee).

Data Set	Measure	Count	Percentage
Selected Data	Reliability	181 (181)	100.00%
Selected Data	Absolute Accuracy (Y)	140 (181)	77.35%
Selected Data	Relative Accuracy (Y)	140 (181)	77.35%
All Data	Reliability	7,509 (7,509)	100.00%

The USDOT number parameter was 100 percent reliable, but only 71 percent accurate. In many instances this was due to the system triggering (i.e., capturing the image of the side of the vehicle) too early and missing the information. This was particularly acute for vehicles with long-cabs.

The reliability and accuracy of the combination of these three parameters is lower than any one parameter taken separately since if just one of these three parameters is not assessed correctly by the system, their combination is deemed unreliable or inaccurate. While the reliability was just below 90 percent, the accuracy of the combination could be as low as 37 percent (absolute) 42 percent (relative), as shown in table 14. Again, nighttime rainy conditions were the worst for system reliability. However, for accuracy the worst case was nighttime clear.

Table 14. License plate information and U.S. Department of Transportation number reliability and accuracy (Unicoi County, Tennessee).

Data Set	Measure	Count	Percentage
Selected Data	Reliability	161 (181)	88.95%
Selected Data	Absolute Accuracy (Y^*+Y)	88 (181)	48.62%
Selected Data	Relative Accuracy (Y^*+Y)	88 (161)	54.66%
Selected Data	Absolute Accuracy (Y)	67 (181)	37.02%
Selected Data	Relative Accuracy (Y)	67 (161)	41.61%

Note: Y^*= 0.

The system deployed at the Unicoi County site showed a 93 percent reliability level at assessing the number of axles that a vehicle had. The accuracy was slightly lower (as low as 91.2 percent), with the worst outdoor conditions for both reliability and accuracy being daytime cloudy conditions.

To analyze the accuracy of the system at determining vehicle weight, the Tennessee Highway Patrol collaborated with ORNL researchers to measure total vehicle weight, as well as axle weight and axle spacing, for randomly selected vehicles that entered the Unicoi County VWS. During the period of June 2016 to September 2016, THP officers manually inspected 149 vehicles that were also inspected by the deployed system. After a first review of the data collected, 69 observations were discarded, either because there was incomplete information provided in the electronic forms or the information in the database of the system was deleted before ORNL could retrieve it (i.e., the system automatically deletes the information when it is ten days old).

Most observations have a gross vehicle weight (GVW) error ranging from -5% to +10%. However, there are several outliers, some of them significantly high (as high as -87%). Also, most of these outliers are on the negative side of the graph, indicating that in these cases the system underestimated the gross vehicle weight, although there were a couple of cases where the error was positive and larger than 10 percent. The conclusion was that, under the assumption that the portable scales used by the THP personnel were error free, the system, on average, did not measure weight correctly.

Conclusion

For both sites, the reliability of the License Jurisdiction parameter was relatively high. However, its accuracy was very low.

In the case of the License Plate Number parameter, its reliability was above 99 percent at both sites (100 percent at Unicoi and 99 percent at Laurel County, where in some cases the license plate was not detected because it was placed on the ventilation grid and not on the front bumper of the vehicle as the system was expecting). The accuracy, however, was much lower. Overall it was 77.4 percent (70 percent during sunny days, worst case) at Unicoi County and 68 percent (worst case 55 percent during the nighttime) at Laurel County.

The USDOT number parameter was 100 percent reliable at the Unicoi site, but only 79 percent at Laurel County. The accuracy of this parameter was low at both sites (71 percent and 59 percent). In many instances this was due to the system triggering (i.e., capturing the image of the side of the vehicle) too early and missing the information.

Some applications of the system studied in this report require matching of the same vehicle at two different sites. The identification of a vehicle would require that the license plate jurisdiction and number, and the USDOT number be accurate. ORNL analyzed this condition. As expected, the reliability and accuracy of the combination of these three parameters is lower than any one parameter taken separately. At the Unicoi County site the reliability was just below 90 percent and it was 70 percent at the Laurel County site. The accuracy of the combination was as low as 30 percent Laurel County, and slightly better at Unicoi County, reaching 37 percent.

The system deployed at Unicoi County showed a 93 percent reliability level at assessing the number of axles that a vehicle had. This parameter had a reliability of 97 percent at Laurel County. The accuracy was about 93 percent at both sites.

To analyze the accuracy of the system at determining vehicle weight, THP collaborated with ORNL researchers to measure total vehicle weight, as well as axle weight and axle spacing, for randomly selected vehicles that entered the Unicoi County VWS. The analysis showed that for GVW the average weight error (system weight minus measured weight as a proportion of the measured weight) was different from zero. That is, the system was bias, and overestimated weight. When each axle weight was evaluated individually, axle 1 presented a strong positive bias (weight was overestimated) when compared to the other axles. Because of this bias, in 90 percent of the cases that were at the vehicle overweight boundary, the system labeled the vehicle as being overweight when it was not, and in 10 percent of the cases it did not flag the vehicle as being overweight when it was.

Regarding axle spacing, the system always provided an additional measurement as if an additional axle existed (e.g., for a five-axle vehicle, the system will provide six spacing distances). When the data was compared with the THP field measurements, the axle 1-2 spacing and axle 3-4 spacing presented average errors (system spacing minus measured spacing and a proportion of the measured spacing) that were different from 0, thus showing a (positive) bias.

In conclusion, the system showed a low accuracy to be used for re-identifying vehicles (i.e., vehicles that are identified at one site with the technology and then identified and matched at another site sometime later). Although the weigh-in-motion component of the system seems to be calibrated within the normal tolerances for these types of devices, axle 1 weight appears to require a different calibration factor than the rest of the axles. This is in an indication that the algorithm used to assign axle weight may need to be revised. Also, if the tested system is used to identify overweight vehicles, a considerable number of false alarms could be expected. And in some cases (10 percent in this analysis), vehicles that are overweight will not be identified as such.

ORNL Recommendations and Response

At the completion of the analysis, ORNL made five recommendations to improve operations at the sites. Those recommendations, as well as responses from the project team, are found below.

- **Recommendation 1—**The image-capturing sub-system triggers too early or does not capture the entire side of a CMV cabin. This was especially pronounced with long cabs, where in many instances the deployed technology is unable to find the USDOT number because the image is not complete. It is recommended that a larger portion of the side of the CMV cabin be captured.
    - *Response 1*—The project team currently implements multiple image capture for our Automated USDOT Reader (AUR), as proposed in the recommendation. When a USDOT number is successfully decoded, the details page will display the image with the decode. If the AUR is not able to decode a USDOT number from the captured images, then the first image from the sequence is displayed. This may have given the researchers a false impression on early triggering. With coordination, the team can enable image capture, and make these image sequences available to ORNL for analysis.
- **Recommendation 2—**In many cases the license plate is not located on the front bumper of a CMV; instead, it is placed somewhere on the grid. The system already has built-in functions that allow it to look for the USDOT number anywhere on the side of the cabin. It is recommended that these functions be used to locate the vehicle license plate, especially if it is not located where it is expected to be.
    - *Response 2*—The cameras supplied currently employ this feature. The project team has realigned the Automated License Plate Reader (ALPR) camera at Laurel County, KY to better capture the vehicles as they travel through the model site.
- **Recommendation 3—**The algorithm used to identify the license plate jurisdiction does not appear to be consistent and/or precise. It is recommended that this algorithm be revised and improved. It is acknowledged that there is a wide variety of license plate layouts and improving this algorithm may be challenging. However, if the technology is to be used to identify vehicles, then the license plate jurisdiction needs to be determined with a higher accuracy than what the deployed system showed.
    - *Response 3*—The project team agrees that relying on the camera jurisdiction reading only is not ideal and is prone to a misidentification of the jurisdiction. This is a persistent problem with most license plate algorithms for jurisdiction. The team has implemented a more accurate method of determining the jurisdiction by simply querying the SAFER database with the license plate number and using that jurisdiction. This provides an error rate of less than 2 percent compared to a much higher error rate from the ALPR only.
- **Recommendation 4—**Although the weigh-in-motion device appears to be calibrated within the tolerances commonly used for those devices, it seems that axle 1 weight

presents problems (i.e., its calibration factor is different from the axles calibration factors). It is recommended that the algorithm assigning weight data be revised, especially with regards to axle 1.

  - *Response 4*—Upon completion of the installation, the project team performed an ASTM 1318 WIM calibration. The project team has since performed additional WIM calibrations, including a front axle weight correction which is commonly used in WIM systems. We have used the data provided by ORNL to adjust the first axle to improve the WIM performance.

- **Recommendation 5—**The system identified an additional axle-spacing measurement after the last axle of CMV vehicles. It is recommended that the algorithm assigning axle spacing be revised and adjusted to consider the number of axles identified for a given vehicle.

  - *Response 5*—The project team logged into both Laurel County and Unicoi County sites and was unable to identify the problem being described.

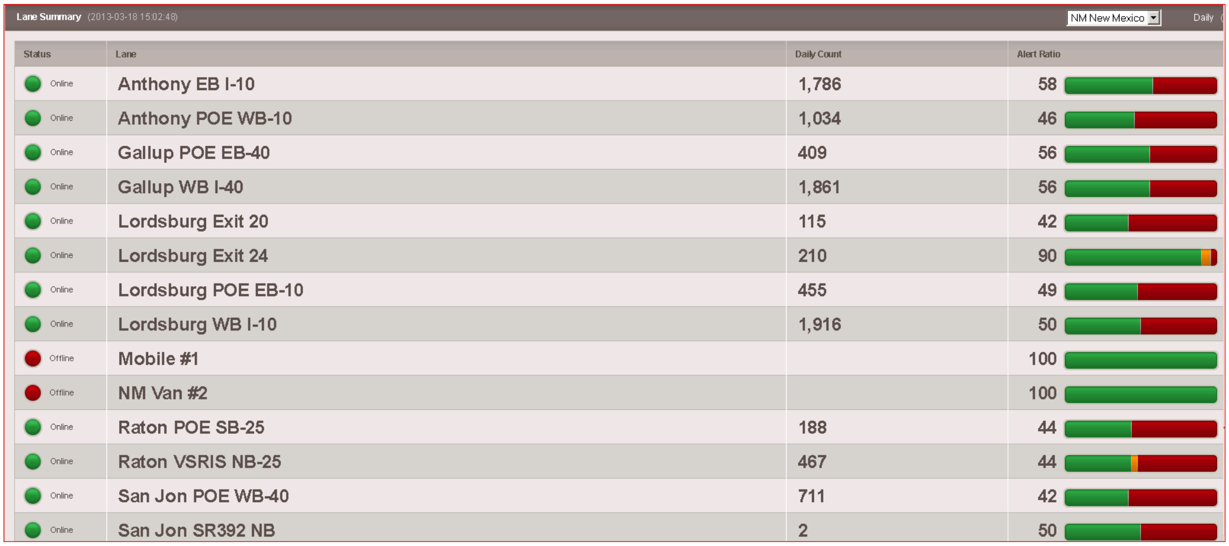
Following the separate and independent ORNL review, the project team was given an opportunity to re-run some of their performance tests to potentially record a higher system performance. However, the project team believes that the recommendations made by ORNL showed gaps in definitions and understanding of the SRIS system operation and thus the ORNL analysis presents differing performance numbers. The project team conducted the initial proscribed performance analysis with results consistent for the site conditions and equipment deployed. The performance numbers officially collected by the team meet the project goals and expectation of the system and continue to do so in subsequent monitoring. The team is pleased with the results of this report and does not feel that a re-run is necessary.

CHAPTER 7. SITE MAINTENANCE AND SUPPORT (TASK 7) AND NEXT STEPS

After the completion of modifications based on the ORNL review, both sites are fully deployed and operating as VWS. As part of this project, the project team will provide three years of support for each virtual weigh station (VWS), including:

- Continuous testing of installed equipment to ensure proper function.
- Monitoring of test metrics to ensure program objectives are met (see Chapter 5 for more detail on key test metrics).
- Calibration services to be performed twice yearly on a semiannual basis.
- Maintenance or repairs necessary to ensure above requirements are met.

Project team technicians will be available for the duration of the test for technical support and issue resolution. The project team will also provide web and telephone support for each site. This support started on May 1, 2016 and is scheduled to run through April 30, 2019.



Status	Lane	Daily Count	Alert Ratio
● Online	Anthony EB I-10	1,786	58
● Online	Anthony POE WB-10	1,034	46
● Online	Gallup POE EB-40	409	56
● Online	Gallup WB I-40	1,861	56
● Online	Lordsburg Exit 20	115	42
● Online	Lordsburg Exit 24	210	90
● Online	Lordsburg POE EB-10	455	49
● Online	Lordsburg WB I-10	1,916	50
● Offline	Mobile #1		100
● Offline	NM Van #2		100
● Online	Raton POE SB-25	188	44
● Online	Raton VSRIS NB-25	467	44
● Online	San Jon POE WB-40	711	42
● Online	San Jon SR392 NB	2	50

Figure 13. Photo. Example electronic screening software dashboard.
(Source: FHWA)

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